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Patentanmeldung Nr. Patent application No. Demande de brevet n°

03255736.5

PRIORITY DOCUMENT

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Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Beam steering apparatus

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Beam Steering Apparatus

Field of the Invention

The present invention relates to beam steering apparatus and is suitable, particularly but not exclusively, for use with antennas arranged to transceive radio frequency signals.

Background of the Invention

Many different signal processing systems are faced with the problem of capturing signals that emanate from different directions. Examples of such systems include Radio Frequency (RF) base stations, air traffic control systems, and satellite systems (to name a few), which either employ mechanical devices comprising an antenna that physically moves in space, or electronic devices comprising antenna elements that apply various phase shifts to incident signals, thereby effectively steering the incident signal. These electronic devices are commonly referred to as phased antenna arrays and are becoming more and more commonly used in RF sensor and communications systems because they do not involve physical motion of the antenna and are capable of moving a beam rapidly from one position to the next.

Phased arrays are conventionally implemented by applying a phase and amplitude weight to an element of an antenna array. By altering the phase slope applied across the array the pointing direction of the beam can be controlled. Alternatively a time delay is applied to an element of an antenna array; an advantage of applying time delays as opposed to a phase shift is that time is frequency independent, whereas phase is frequency dependent (for two different frequencies, the same amount of phase is equivalent to two different amounts of time and thus two different beam directions; if two signals of different frequencies are received and processed at the same time, this same amount of phase will result in the beams being steered in two different directions).

Antennas that are designed to instantaneously receive signals over a broad range of frequencies typically apply an amount of time to each element instead of an amount of phase, since this enables incident beams to be steered independently of their respective frequencies. Time delay systems essentially comprise time delay units having transmission lines of varying lengths and incoming signals are passed through various lengths in order to modify the direction of the beam. Conventional systems typically include digital devices that switch in these transmission lines, effectively adding discrete time delay "bits" to the beams. A problem with these systems is that the transmission lines occupy physical space, and, for a large array of antenna elements, many different lengths of transmission lines are required, which results in bulky and costly arrangements.

An object of the invention is to provide a more compact beam steering apparatus.

Summary of the Invention

According to an aspect of the invention there is provided beam steering apparatus comprising:

an antenna array having a plurality of antenna elements, the antenna elements being spatially arranged with respect to one another and being operable to transceive signals; and

delay circuitry arranged to apply an amount of delay to signals transceived by the antenna elements, the delay circuitry comprising:

a plurality of first delay units, each of which is connected to a different one of the antenna elements, and is operable to selectively apply either a first amount of delay or a second amount of delay to signals passing therethrough; and

a plurality of second delay units, each of which is connected in series to at least one of the first delay units and is operable to selectively apply either a third amount of delay or a fourth amount of delay to signals passing therethrough,

wherein at least one of said second delay units is connected in series to at least two of the first delay units.

Thus in embodiments of the invention a given second delay unit is effectively re-used by a plurality of first delay units, which means that duplication of second delay units is minimised. In the event that the antenna array comprises a significant number of antenna units, and the delay circuitry comprises a corresponding significant number of first delay units, the delay circuitry preferably comprises further delay units arranged in series with the second delay units, and each further delay unit is connected to at least two second delay units. Thus this feature of re-use of time delay units is reproduced by each set of time delay units.

In one embodiment the delay circuitry is provided by a plurality of switches arranged in series with one another, and a first difference between the first and second amounts of delay is different to a second difference between the third and fourth amounts of delay. In preferred arrangements the second difference is greater than the first difference, and the signals modified by the said at least two first delay units are combined prior to further modification by the second delay unit.

In one embodiment the signals are passed between within the delay circuitry via cables. However, in a preferred embodiment the transmission medium used is optical fibre, which, in comparison with cables has a reduced amount of relative loss and dispersion effects associated therewith, and provides a physically compact and stable solution that is resistant to electro-magnetic interference. Accordingly the beam steering apparatus includes signal modulating means arranged to modulate the signals transceived by antenna elements. In one arrangement the signal modulating means comprises a plurality of signal modulating devices, each of which is arranged to modulate signals transceived by a different antenna element onto said respective optical carrier. Each optical carrier has a different frequency to that of the other carriers and can be provided by a laser.

In this embodiment, signals modified by the first units are collected into the same waveguide prior to modification by the second unit, and are only combined when the second time delay unit has applied the third or fourth amount of time delay. The beam steering apparatus comprises a demultiplexing device arranged to separate out the respective carriers from the waveguide, and a demodulating unit arranged to demodulate the carriers from the optical domain into the radio frequency domain, at which point the signals are combined.

Further features and advantages of the invention will become apparent from the following description of preferred embodiments of the invention, given by way of example only, which is made with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1 is a schematic diagram showing a conventional phased antenna array;

Figure 2 is a schematic diagram showing a first embodiment of a beamformer according to the invention;

Figure 3 is a schematic diagram showing an alternative arrangement of the beamformer of Figure 2; and

Figure 4 is a schematic diagram showing a second embodiment of a beamformer according to the invention.

Detailed Description of the Invention

Figure 1 shows a wavefront 10 incident on a beam steering apparatus implemented as conventional phased antenna array 1. In such known arrangements the antenna array 1 comprises a plurality of antenna elements 100a, 100b, 100c, 100d, each of which is arranged to apply a certain amount of time delay to the part of the wavefront impinging thereon. The amount of time delay applied by each element is dependent on the shape of the wavefront and on the angle that the wavefront makes with respect to the antenna elements (referred to herein as direction of arrival of the wavefront); as can be seen from

Figure 1, different amounts of time delay are applied to each element, and the difference between the amounts of time delay applied by respective antenna elements is greatest between peripheral antenna elements 100a, 100d.

In this conventional arrangement, each antenna element 100a, 100b, 100c, 100d is connected to a plurality of delay units such 101a, 103a ... 101d, 103d that are arranged in series. Note that the embodiment shown in Figure 1 is illustrative only; in practice many more antenna elements will be used. When embodied as a two way switch, at any instant of time each delay unit is arranged to apply one of two amounts of time delay – here 0 and L for first delay units 101a ... 101d, and 0 and 2L for second delay units 103a ... 103d. Thus, in this example the first and second amounts of delay are 0 and L and the third and fourth amounts of delay are 0 and 2L respectively. It should be noted that the arrangement shown in the Figure is ideal since it implies that multiples of delay L compensate precisely for corresponding multiples of D.

In the Figure the signal path taken through a switch is indicated by a solid line. Thus in this example the incoming wave 10 is effectively steered by applying a delay of 0 to the wave received by antenna element 100a, by applying a delay of L to the wave received by antenna element 100b, by applying a delay of 2L to the wave received by antenna element 100c, and by applying a delay of 3L to the wave received by antenna element.

The degree of time delay control is dependent on the delay applied by the time delay units (here switches 101a ... 103d), and selection of this degree of time delay control is dependent on a minimum acceptable quality of beam shape, which is governed by the maximum time delay error that can be suffered at each element. In the example shown in Figure 1, the smallest amount of time delay that can be applied is L, so the antenna array 1 can compensate for the direction of arrival of the wavefront with an accuracy of 1L.

It will be appreciated that, as the angle between the wavefront and the antenna elements 100a ... 100d increases, the difference between the amounts of time delay applied at peripheral antenna elements 100a, 100d has to increase correspondingly. Furthermore, if the wavefront is to be steered at

various positions along its length, the antenna array 1 will have to comprise many time delay units in series with one another, which means that the antenna array 1 can be quite large and complex. Moreover, if fine-tuning of the time delay control is required (meaning that the amount of delay (L) applied by the first time delay units 101a ... 101d is small), even more delay units will be required.

Embodiments of beam steering apparatus according to the invention will now be described with reference to Figures 2 and 3. Turning firstly to Figure 2, in a first embodiment of the invention, referred to herein as a beamformer, the beamformer 2 comprises a plurality of first delay units 101a ... 101d, each of which is arranged to apply an amount of time delay to signals transceived by a respective antenna element, and a plurality of second delay units 203a, 203b, each of which is arranged to apply an amount of time delay to signals that have been modified by the first delay units 101a ... 101d. At least one 203a, and preferably both 203a, 203b, of the second units are connected to two first delay units 101a, 101b via a combiner unit 205a, 205b, which, in the case of combiner unit 205a, is arranged to combine signals that have been modified by the associated first delay units 101a, 101b, and in the case of combiner unit 205b, is arranged to combine signals that have been modified by the associated first delay units 101c, 101d. Preferably the combiner units 205a, 205b sum the modified signals, and pass them onto the second delay units 203a, 203b, which proceed to apply a further delay to the signals. These further modified signals are then combined in another combiner unit 207, summing the further delayed signals.

Turning again to Figure 1, it can be seen that when the antenna array 1 is applying 0, L, 2L and 3L delay to signals transceived at respective antenna elements 100a ... 100d, second switches 103a, 103b assume the same switch position as one another (in this example 2L), and second switches 103c, 103d assume the same switch position as one another (in this example 0). By use of the present invention, the duplication of delay units is reduced, which means that the antenna array includes fewer delay units. As a result, antenna arrays

can be produced according to the invention, which are less bulky, complex and costly than those currently utilized.

In the example shown in Figure 2, there are only four antenna elements, and, since the first delay units 101a ... 101d are embodied as two-way switches (meaning that each combiner unit 205a, 205b receives input from two first units), the beamformer 2 only comprises two levels of delay units. However, in practical embodiments of the invention, beamformers comprise a significantly greater number of antenna elements, which means that the number of levels of delay units will increase accordingly. Figure 3 shows an example where the beamformer comprises eight antenna elements 100a ... 100h and three levels of delay units (101a ... 101h, 203a ... 203d, 209a and 209b). The improved efficiency, in terms of reduction of duplicated delay units (and corresponding re-use or "sharing" of amounts of delay) can be readily appreciated with increasing numbers of antenna elements and amounts of delay required.

In one embodiment the signals are passed between delay units 101a ... 101d, 103a ... 103d and combiner units 205a, 205b via cables. However, in a further embodiment the transmission medium used is optical fibre, in order to reduce relative losses and dispersion effects, and to provide a physically compact and stable solution that is resistant to electro-magnetic interference.

Figure 4 shows a further embodiment of the beam steering apparatus according to the present invention. Transceived Radio Frequency (RF) signals are in this embodiment modulated onto an optical carrier by laser devices 413a ... 413d, and the (first and subsequent) delay units 401a ... 401d, 403a ... 403d, etc. are preferably embodied in Opto Electronic Integrated Circuits (OEIC). Each transceived signal is modulated onto an optical carrier having a wavelength, for example, in the 1300 nm or in the 1550 nm band.

The summation of signals performed by respective combiner units 405a, 405b, 407 etc. can be performed in the optical domain, but more preferably is performed in the RF domain because RF signals have a far longer wavelength (thus more relaxed accuracy requirements) than that of optical carriers. In one arrangement the signals can be summed, as described above with reference to

Figures 2 and 3, at each combiner unit, which involves demodulating and re-modulating the RF signals from their respective carriers at each combiner unit (meaning that the combiner units will require the corresponding modulating and demodulating capabilities). Preferably, however, the signals are merely collected by combiner units 405a, 405b in the optical domain and are only summed when the collected signals have been separated out and demodulated into the RF domain. This means that only one device is required to have demodulating capabilities.

Accordingly, in this arrangement each transceived signal is modulated onto an optical carrier of a different wavelength, and each combiner unit 205a, 205b, 207 etc. is arranged to input signals received from its associated first units 101a, 101b into the same waveguide. Wavelengths in the 1300 nm and 1550 nm bands can be used, and the wavelengths are spaced apart so that there is no interference between the carriers (e.g. spacing between 0.1 nm and 14 nm can be used). The combined signals pass through the next and, if relevant, successive delay units 403a, 403b as described above with reference to Figure 2, with identical time delays being applied to those wavelengths passing through the same delay unit. The beamformer 2 may also comprise a final combiner 407 and a conventional wavelength demultiplexing device 415 that is arranged to demultiplex the wavelengths at the output using conventional wavelength demultiplexing techniques. These demultiplexed signals can then be demodulated and summed in the RF domain using a suitable device, shown as part 417.

Whilst in the above embodiments the time delay units are two-way switches, they could alternatively be switches comprising three or more switching paths. In this case, the combiner units can be arranged to receive input from a corresponding three or more first units.

Whilst in the second embodiment the delay units are provided by OEIC, they could alternatively be provided by suitable mechanical switches.

Whilst in the above embodiments the entire beamformer is shown to be configured in accordance with the invention, the hierarchical arrangement of

first delay units and second delay units could alternatively be applied to a selected part of the beamformer.

Whilst in the above embodiments the delay unit arrangement includes one switchable delay unit at each node, the arrangement could alternatively comprise a plurality of two-way switchable delay units arranged in series at each node in at least the highest level nodes of the hierarchy (the antenna element level.) Each such a series would consist of delay units having progressively smaller time delay differences between their two respective settings (e.g. L, L/2, L/4, etc.), whereby a variety of time delays may be applied at selected increments (e.g. L/4) at each element. Thus, a variety of beam steering angles may be achieved by selecting appropriate settings for each of the switches in each of the series.

Whilst in the above embodiments the combiner units 205a ... 205d, 207a, etc. are shown to be separate from respective second delay units 203a ... 203d, 209a, 209b, they could alternatively be an integral part of the second delay units.

Whilst in the Figures the antenna elements 100a ... 100d are shown spaced in a linear array, they could alternatively be spaced in a circular array or a planar array.

The above embodiments are to be understood as illustrative examples of the invention. It is to be understood that any feature described in relation to any one embodiment may be used alone, or in combination with other features described, and may also be used in combination with one or more features of any other of the embodiments, or any combination of any other of the embodiments. Furthermore, equivalents and modifications not described above may also be employed without departing from the scope of the invention, which is defined in the accompanying claims.

Claims

1. Beam steering apparatus comprising:

an antenna array having a plurality of antenna elements, the antenna elements being spatially arranged with respect to one another and being operable to transceive signals; and

delay circuitry arranged to apply an amount of delay to signals transceived by the antenna elements, the delay circuitry comprising:

a plurality of first delay units, each of which is connected to a different one of the antenna elements, and is operable to selectively apply either a first amount of delay or a second amount of delay to signals passing therethrough; and

a plurality of second delay units, each of which is connected in series to at least one of the first delay units and is operable to selectively apply either a third amount of delay or a fourth amount of delay to signals passing therethrough,

wherein at least one of said second delay units is connected in series to at least two of the first delay units.

2. Beam steering apparatus according to claim 1, wherein a first difference, between the first and second amounts of delay, is different to a second difference, between the third and fourth amounts of delay.

3. Beam steering apparatus according to any one of the preceding claims, wherein the said second difference of delay is greater than the said first difference.

4. Beam steering apparatus according to any one of the preceding claims, arranged to combine the signals modified by the said at least two first units and to apply either the third or fourth amount of delay to said combined signals.

5. Beam steering apparatus according to any one of the preceding claims, including signal modulating means arranged to modulate signals transceived by each of the antenna elements onto a respective carrier.

6. Beam steering apparatus according to claim 5, wherein the signal modulating means comprises a plurality of signal modulating devices, each of which is arranged to modulate signals transceived by a different antenna element onto said respective carrier.

7. Beam steering apparatus according to claim 6, wherein the signal modulating means is arranged to input each of said carriers into a different one of said plurality of first units, for delay of the signal therein.

8. Beam steering apparatus according any one of claim 5 to 7, wherein the signal modulating means is arranged to modulate said signals onto an optical carrier.

9. Beam steering apparatus according to claim 8, wherein the data signals modified by the at least two first units are collected within a single optical waveguide and are input to said first second unit.

Abstract

Beam Steering Apparatus

Embodiments of the invention are concerned with beam steering apparatus comprising:

an antenna array having a plurality of antenna elements, the antenna elements being spatially arranged with respect to one another and being operable to transceive signals; and

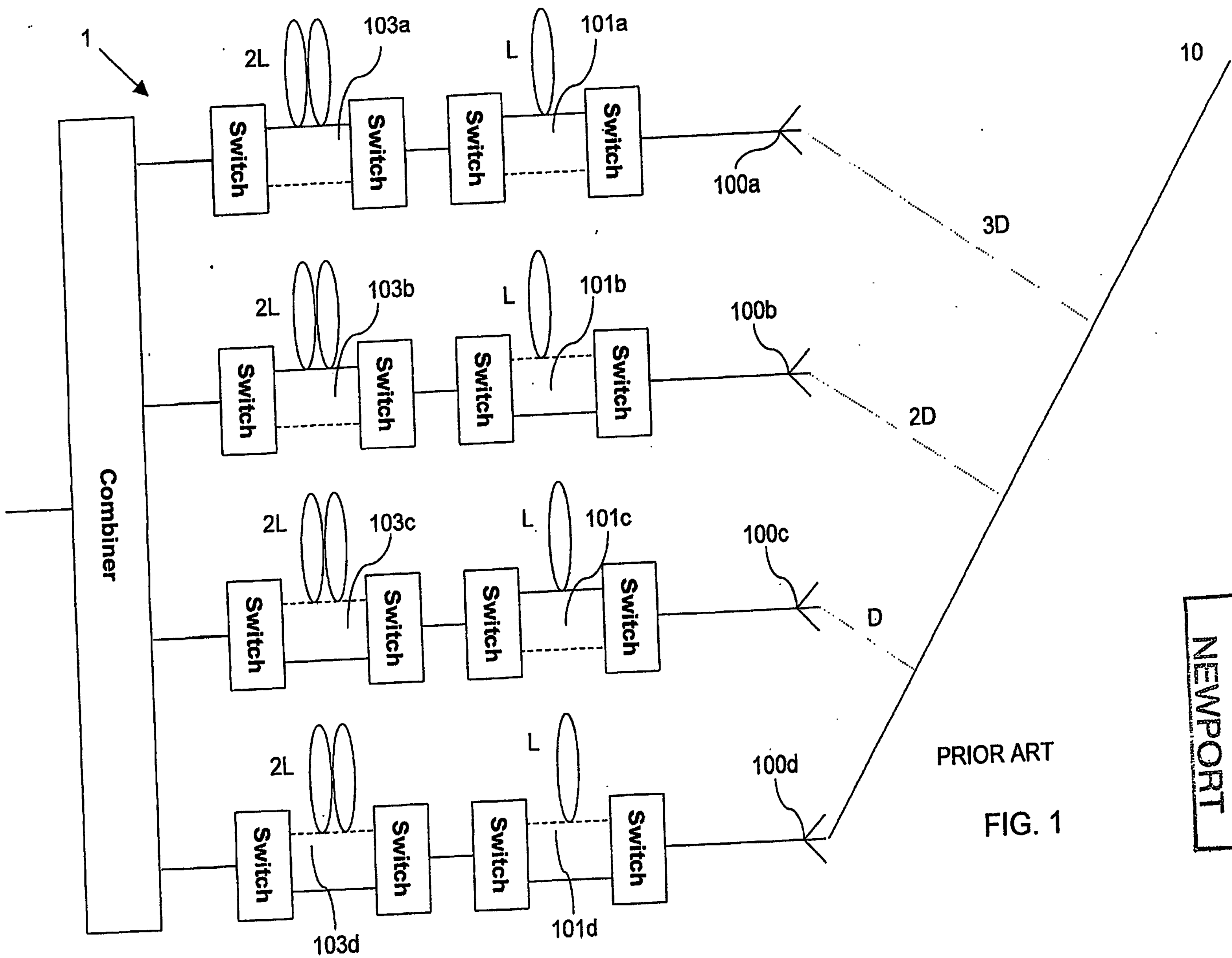
delay circuitry arranged to apply an amount of delay to signals transceived by the antenna elements, the delay circuitry comprising:

a plurality of first delay units, each of which is connected to a different one of the antenna elements, and is operable to selectively apply either a first amount of delay or a second amount of delay to signals passing therethrough; and

a plurality of second delay units, each of which is connected in series to at least one of the first delay units and is operable to selectively apply either a third amount of delay or a fourth amount of delay to signals passing therethrough,

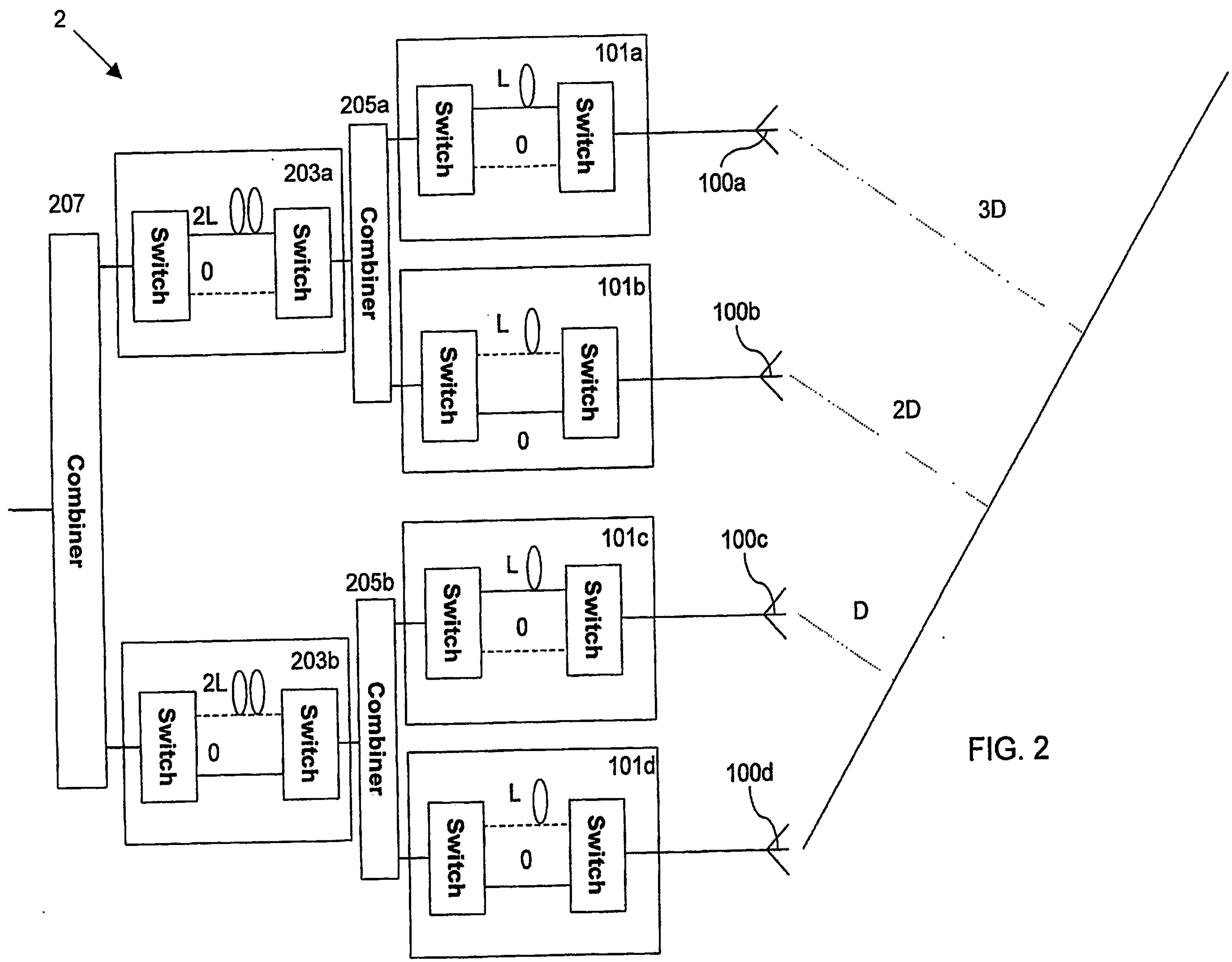
wherein at least one of said second delay units is connected in series to at least two of the first delay units.

Figure 2



PRIOR ART

FIG. 1


2
207
Combiner
203a
Switch
2L
0
Switch
205a
Combiner
101a
Switch
L
0
Switch
100a
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Switch
L
0
Switch
100b
2D
203b
Switch
2L
0
Switch
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L
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100c
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Switch
L
0
Switch
100d

FIG. 2

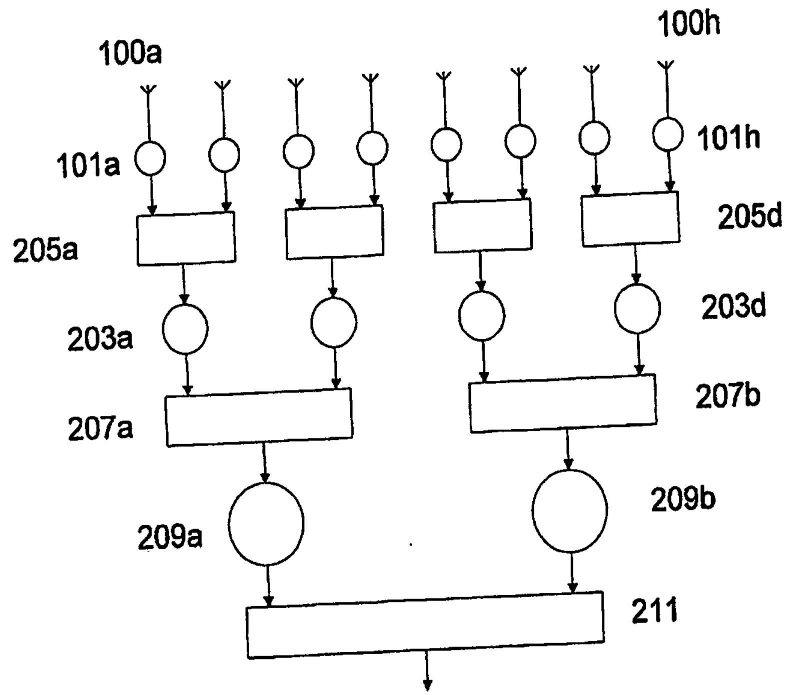
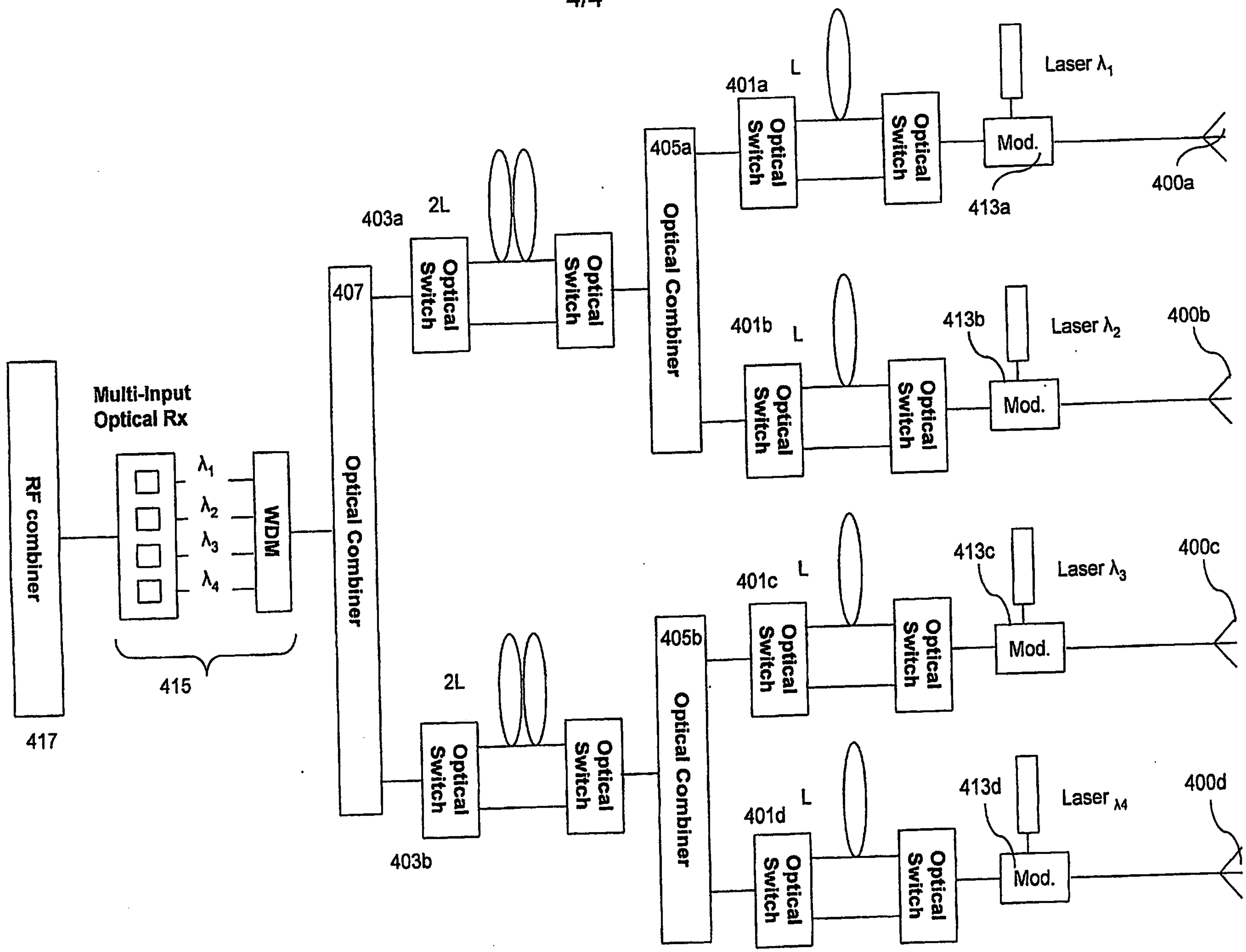

100a
100h
101a
101h
205a
205d
203a
203d
207a
207b
209a
209b
211

FIG. 3



Laser λ_1
Laser λ_2
Laser λ_3
Laser λ_4
Mod.
413a
413b
413c
413d
400a
400b
400c
400d
Optical Switch
L
401a
401b
401c
401d
Optical Combiner
405a
405b
2L
403a
403b
Optical Combiner
407
WDM
λ_1
λ_2
λ_3
λ_4
Multi-Input Optical Rx
415
RF combiner
417

FIG. 4